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Study of the Southern Gulf of St. Lawrence Cod Population

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The fishery

Cod have been fished in ice-free months in the southern Gulf of St. Lawrence for more than a century. Up to 1947 the method of fishing was by baited hook or jigger but at that time a major change took place with the introduction of otter trawling by Canadians. This change, plus additional fishing by European otter trawlers starting in 1952, had a marked effect on the population in the area.

Tagging experiments reported by McCracken (1959) and Martin and Jean (1964) have shown that the Gulf of St. Lawrence cod population is a migratory stock. The general pattern of migration is shown diagrammatically in Fig. 1. There are two main areas where the fish appear to congregate and where the fishery on them is concentrated. These are the Magdalen Shallows area between the Magdalen Islands and Cape Gaspe-Bay Chaleur area, and secondly, the edge of the Laurentian Channel off the northeast coast of Cape Breton. The annual migratory pattern is from the Magdalen Shallows area in the fall to the area of winter concentration near Cape Breton and back again to the Magdalen Shallows area in the spring.

Research vessel surveys using an otter trawl having a small-mesh lining in the codend indicate that the migratory habit is more pronounced in the older fish. This is reflected in differences in size and age composition in the winter and summer areas. The samples taken represent both pre-commercial and commercial sizes and ages to be found in the area. The differences are represented in Fig. 2. The upper part of the figure shows samples taken in the Cape Breton area in the winter. When they are compared with those in the lower part of the figure from the southwestern Gulf, it can be seen that the former group is composed of longer, older fish.

Fishing fleets have taken advantage of these migrations and concentrations, particularly during the last 15 years. The Canadian otter-trawl fleet tends to concentrate its fishing activity on the stock when it is in the Magdalen Shallows area whereas other nations fish it when the cod are concentrated along the edge of the Laurentian Channel north of Cape Breton in the winter.

The annual landings of cod from this population by Canada and other countries are shown in Fig. 3. The early statistics for the years 1936-51 show a wholly Canadian catch, fluctuating between about 20 thousand and 53 thousand metric tons. The introduction of otter trawling and the activities of other countries led to a rapid rise in landings to a peak in 1956 of 110 thousand metric tons. The total has since decreased and seems to be levelling off at somewhere between 60 and 65 thousand metric tons, partly on account of decreases in landings by France, Portugal, and Spain during the 1960-65 period.

Canadian landings peaked at about 69 thousand metric tons in 1957, dropped fairly rapidly to 40 thousand metric tons in 1960, and increased again to about 56 thousand metric tons in 1965. Since its introduction, otter trawling has become progressively more important, and this is particularly noticeable in the figure from 1956 onwards. Since that time, landings by other Canadian gears which are mainly various types of line fishing have decreased each year. It should be noted in the figure that, although otter trawling and Danish seining are combined, Danish seining is still a very small part of this, less than 5%.

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During the last 15 years there have been changes in the size and age composition of the cod population. Figure 4 shows size composition of landings of cod for the 1949-51, 1956-57, and 1962-65 periods. In the earlier years, 1949-51, a group of fish was being landed with a peak size at 61 cm. This is shown in the top of the figure. During 1956-57 the mean size landed was particularly high, and as will be shown later, this was a period of accelerated growth of these cod. The more recent years are shown in the bottom of the figure, with an average for 1962-65. It is apparent that recently the bulk of the fish landed are between 37 and 70 cm in length, with a usual peak size at 46 cm.

Comparable age compositions are shown in Fig. 5. For the earlier years and during the fast-growth period the dominant age group was 7-year-olds. Also, there were fair numbers of fish landed that were 10 years of age or older, particularly in 1949-51. The figure shows that during more recent years the usually dominant age group has been 6-year-olds. Data for 1965 and 1966 show the catch to be predominantly 4-year-olds. The number of fish over 10 years of age in the landings has decreased markedly. Both Fig. 4 and 5 were calculated on a numbers-of-fish-per-trip basis for Gloucester-class draggers (25-50 tons). The numbers in brackets in Fig. 4 and 5 giving catch per trip in numbers for the three periods provide an interesting comparison of the smaller numbers of fish per trip landed from the years in which the fish were larger and older and the recent much larger numbers landed in years in which the fish are smaller and younger.

The change in size composition of the catch has affected the numbers of fish discarded at sea by fishermen. Trips to sea by staff of the Biological Station have helped to keep track of the changes in discard practices. Data on discards at sea are shown in Table 1.

Table 1. Average discards of cod catches at sea in ICNAF Division 4T.

Year	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965
Av. % of numbers discards	22.9	21.1	16.9	10.4	10.5	4.6	3.0	3.0	1.6	1.0
Mesh size (inches)	3	3-4½	4-4½	4½-4$\frac{7}{8}$	4$\frac{3}{8}$-4½	4$\frac{3}{8}$	-	4½	4$\frac{1}{8}$	4$\frac{1}{8}$-4 $\frac{5}{8}$

Average % discarded by age 1949-56	Age 2 & under	3	4	5	6
	18	39	40	3	0

Their numbers have decreased yearly since 1956. Initially high discards were partially due to the small mesh being used by these draggers, but after 1959 when mesh regulation became strictly enforced, the annual decrease in discards continued. This was mainly due to a gradual change in acceptable sizes of fish at fish plants handling the catch from the 4T cod population. Acceptable size has decreased as the availability of large cod has gone down. Average age composition of discards for the years 1949-56 is shown in the bottom panel of Table 1. It shows discards to be under age 6 and this has continued to be the case in subsequent years.

Change in availability of fish is reflected in landings-per-unit-effort data in Fig. 6. Long-term data for the Canadian otter-trawl fleet are available since the start of dragging by Canadians. The overall trend from 1948 to 1964 for Canada is a downward one although a low was reached in 1960 and since then there has been an increase. Catch-per-unit-effort data for Portugal and Spain are also available from ICNAF statistics and follow a similar trend from 1954 to 1960 but take a marked upswing from that time until 1963. This upswing appears to be due to the fact that this fleet now fishes the population only when it is densely concentrated in the Cape Breton area, and this is borne out by the total decrease in foreign landings shown in Fig. 3.

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The catches per trip for survey cruises are compared with those for commercial vessels in Fig. 7. It is of interest to note in Fig. 7 that surveys carried out by the St. Andrews Biological Station on an annual basis on this cod population when it is in the Magdalen Shallows area produce abundance trends which are very similar to those taken from commercial otter-trawl landings. The survey is undertaken each fall by a vessel similar in size to most of those used by the northern New Brunswick otter-trawl fleet and provides a forecast of availability and sizes for the following year. The value for 1957 may be unrealistically high due to a conversion factor used for surveys by a smaller boat during that year (see Jean, 1964). However, trends in availability from the two sources are very similar from 1958 on.

As mentioned earlier, a further factor affecting sizes and age of cod landings from the Gulf stock has been changes in growth. This is illustrated in Fig. 8 where mean sizes of age groups from 6 to 10 have been plotted for the years 1949-65. The data were taken from commercial landings. A peak size-at-age is shown in the 1956-57 period and has been mentioned previously; this was due to a marked increase in growth. The main reason for this increase appeared to be a mass herring mortality discussed in an earlier paper (Kohler, 1963). More recent age/length data show that average size-at-age has been dropping steadily since the fast-growth period and the lack of larger fish in the landings has made averages for 9- and 10-year-olds less realiable. The figure indicates some evidence of levelling off of 6-, 7-, and 8-year olds at their present growth, and, although this is not as high a mean length-at-age as was apparent in the 1949-53 period, the spacing of the points for the various age groups indicates that the rate of growth of commercial size fish is about as fast if not faster than in 1949-53.

Studies carried out during the aforementioned surveys since 1959 have indicated some changes in volume and species of food taken by these fish which could partially account for growth change. However, details of this analysis will be the subject of another paper. In addition, studies of average size and age at maturity carried out at the same time show fluctuations from year to year in these values, with some tendency toward lower values recently.

Use of data

In the foregoing section and in the ones that follow, certain statistics of the fishery have been used and some explanation of the manipulation of them is warranted. The length and age sampling of commercial landings was carried out by technicians from the Biological Station. A variety of size categories are sorted and landed, and these have to be weighted in the samples according to the total landings of the size category of that particular gear during the year. Data for 1954 commercial landings and some for 1953 were not used in this study because of inadequacies in weighting except in some time series where they were essential and had to be interpolated. Seasonal age and length compositions were combined by weighting them according to total landings per season to give a yearly frequency to arrive at an average length composition per season. Fish measured for length were then further sampled for age to arrive at an age/length key. Application of the age/length key to seasonal length frequencies gave us then the age composition of landings per season and per year. Table II lists the estimated age composition for years from 1949-65 on a number of fish per trip basis.

Because of the migration pattern shown in Fig. 1 landings from the Cape Breton area had to be included in order to show a picture of the take from the total population after otter trawling started (Fig. 3). This was done by adding landings for ICNAF Div. 4V for 1952-53, by adding first quarter 4Vn and 4V (4Vs was not included) for 1958-59, and by adding first quarter 4Vn only from 1960 on. These were added to all 4T annual landings. This last breakdown is given for the 1960 onwards period only because prior to that 4Vn was not available separately in ICNAF statistics.

Catch-per-unit-effort data for Canadian otter trawlers were obtained from a log and interview system carried out by technicians of the Biological Station. Most of the Canadian boats fishing the Gulf area and landing in the past years in the Maritime Provinces are between 25 and 75 gross tons. Furthermore, the pattern of fishing has been fairly similar from year to year. Studies have shown that the length of their trips is usually a week and that this varies little over the course of the fishing season. Since there has been no

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appreciable change in the average length of time of a trip, we have taken number of trips as our measure of effort for the Gloucester-class boats.

The catch per trip for Gloucester-class boats has been tabulated in Table III, column 5. The total landings from the stock have then been divided by the catch per trip figure for Gloucester-class boats to arrive at an estimated number of trips per year as if all the landings had been made by boats in this class. Details of the calculations are shown in Table III.

Mortality rates

Catches per effort at age (Table II) and estimated total efforts (Table III) may be used to calculate mortality rates. For that purpose we put

i	subscript referring to age
j	subscript referring to year
${}_iC_j$	catch
f_j	relative effort
q	catchability coefficient
M	instantaneous natural mortality rate
F_j	instantaneous fishing mortality rate
${}_iZ_j$	total instantaneous mortality rate

Making the customary assumptions that the instantaneous fishing mortality rate is proportional to effort, i.e.,

$$F_j = qf_j$$

and that the natural mortality rate is constant, we may put (Paloheimo, 1961)

$$(1) \quad {}_iZ_j = \log \frac{{}_iC_j/f_j}{{}_{i+1}C_{j+1}/f_{j+1}} = q(\tfrac{1}{2})\,(f_j+f_{j+1}) + M$$

Table IV gives the values of total mortality rates ${}_iZ_j$ for pairs of age groups 6/7, 7/8, 8/9, and 9/10 as well as the mean efforts $\frac{1}{2}(f_j+f_{j+1}) = \bar{f}_j$.

To determine whether the instant mortality rate is dependent on effort f_j as suggested by equation (1), a covariance analysis has been carried out on values given in Table IV. The results are exhibited in Table V. The table shows that the regression of ${}_iZ_j$ on $\bar{f}_j$ is not significant for any of the pairs of age groups, and, in fact, the value of the regression coefficient, q in equation (1), has a negative sign for ages 7/6 although it is not significantly different from zero.

To confirm the results of the covariance analysis the data in Table III were divided into three groups: the earlier years from 1949-52 when total fishing effort was less than three thousand units; the transitory period 1954-55; and the later years from 1956-65 when the effort was mostly above six thousand units. Mortality data pertaining to the first and third groups were then subjected to analysis of variance to see if data would indicate any significance between the two groups, one representing a period of low and the other a period of high fishing effort. The results are shown in the bottom panel of Table VI and do not show statistically significant differences between the mortality rates between the two periods.

Although statistically not different, the mean values Z = 0.32 and Z = 0.51 for 1949-52 and 1955-65 differ appreciably. Using these average values of Z and mean effort figures for the same period in equation (1) we get

$$0.32 = M + q\,2809$$
$$0.51 = M + q\,6799$$

Solving the above for q and M we get M = 0.19 and q = .000048 and hence

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$F = 0.13$ ($= q\bar{f}$) for 1949-52 and $F = 0.32$ for 1955-65. These values for fishing mortality rate are somewhat too low to be consistent with the appreciable differences in the age and length compositions observed since the introduction of trawl fishing.

Estimates of total mortality rates by use of equation (1) and Table IV may be contrasted with the estimates of total mortality rates from the catch curve. By calculating an average number of fish caught per trip at age for the periods 1949-52 and 1955-65 and estimating the average decline of the abundance at age, we get the estimates of the total mortality shown at the bottom of Table V. The estimates are obtained from the slope of line giving best fit to logarithms of the average catches per trip at age.

While the total mortality figures based on a catch curve are rather unrealiablw since they reflect not only the mortality rate but also any trend or fluctuation in the recruitment, yet the contrast between the two sets of mortality figures, one showing a marked influence of fishing on the stock and the other a less evident effect, calls for an explanation.

Returning to mortality estimates based on catch and effort data, we recall the analysis of variance of total mortality rates shown in Table VI. While the covariance analysis failed to show a significant regression of total mortality on effort, yet the analysis of variance indicates significant differences between years. We thus conclude that there are year-to-year variations in the catchability, q, or natural mortality, M, which are greater than trends in the total mortality due to increased fishing.

Table VI also shows that there are significant differences between pairs of age groups in the total apparent mortality rate. This could be attributable either to changes in q or M with age. Assuming different q and M at each age, equation (1) now takes the following form:

$$(2) \qquad {}_iZ_j = \log q_i/q_{i+1} + \tfrac{1}{2}q_i f_j + \tfrac{1}{2}q_{i+1} f_{j+1} + \tfrac{1}{2}(M_i + M_{i+1}).$$

Summing (2) over all years i and putting approximately

$$\sum_1^{n-1} f_j \sim \sum_1^{n-1} f_{j+1}$$

we get

$$\frac{1}{n-1}\Sigma_i Z_j = \log q_i/q_{i+1} + \frac{q_i + q_{i+1}}{2}\,\frac{\Sigma f_j}{n-1} + \tfrac{1}{2}(M_i + M_{i+1}).$$

The last two terms represent the average mortality at ages i and i+1 and the first term, $\log q_i/q_{i+1}$ represents a bias in the estimate.

If the catchability is increasing with age, i.e., if $q_i \quad q_{i+1}$ as suggested by figures in Table IV, then the bias term $\log q_i/q_{i+1}$ takes a negative value and we thus get an underestimate of the mean mortality rate for the age groups. This could account for some of the differences in the mortality estimates based on catch-effort on one hand and catch-curve on the other.

Since our studies have indicated that the catch-ability coefficient q and possibly the natural mortality rate M, change both with age of fish and year, a more specific model than equation (1) incorporating these changes was developed. Let

$$a_i = \text{relative catchability of the } i^{th} \text{ age group}$$

$$q_j = \text{catchability in the year } j$$

where we may take, say $a_9 = 1$ as a base line, then equation (1) may be written as

$$(3) \qquad {}_iZ_j = \log a_i q_j / a_{i+1} q_{j+1} + M + \tfrac{1}{2} a_i q_j f_j + \tfrac{1}{2} a_{i+1} q_{j+1} f_{j+1}.$$

The parameters a_i, q_j, and M in (3) could be estimated by first obtaining approximate values for them and then calculating least squares corrections for the initial

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estimates by linearizing equation (3) for the corrections. To obtain meaningful values it would be essential that most correlation coefficients between, say, ${}_iZ_j$ and ${}_kZ_j$ over years j, and ${}_iZ_j$ and ${}_iZ_e$ over ages i are significant. Some sample values are listed below. The listed values of the correlation coefficient fluctuate widely; hence no further attempts to arrive at specific values of q and M were made.

Correlation coefficients between years and ages: Between years: Years 1949-50 and 50-51 marked as 1950, etc.

	1950	51	52	53	54	55	56	57	58	59	60	61	62	63	64
r =	.80	-.88	.14	-.79	.22	.41	.94	.94	.91	.26	.42	.48	-.80	.16	.22

Between ages:

	7/6 & 8/7	8/7 & 9/8	9/8 & 10/9
r =	.60	.57	.18

It is rather surprising that the effect of a twofold increase in effort cannot be demonstrated in our mortality estimates. While the sampling error is probably quite large, one suspects that it does not account for all the variability in the data. We expect in fact that as an important addition to sampling error, our failure to estimate the components of the total mortality arises from deviations from the basic equations (1) or (3) and possibly also from compensation by the fish stock to changes in the amount of fishing effort. These are examined in more detail in the next sections.

Changes in fish stock

Recruitment

The increased fishing on the Gulf of St. Lawrence cod stock has resulted in increased landings and apparently in concommittant changes in ages and lengths landed. Such changes in ages and lengths landed are expected on the basis of catch-per-recruit models. However, there have been other changes in this fish population which are not so readily predictable.

In Fig. 9 we have plotted the catch per trip of 6- and 7-year-old cod. The figures given are three-year running averages with mid points ranging from 1950-64. Regarding the catch per unit of effort of 6-year-olds as indicative of their abundance, Fig. 9 suggests that recruitment to the fishery at age 6 has increased since about 1959, that is, that 1953+ year-classes have in general been more abundant than year-classes prior to 1953.

The abundance of a year-class at age 6 not only reflects the initial abundance of the year-class but also the amount of fish taken from it at earlier ages. Since prior to the introduction of a larger mesh size in 1957-58 more fish were presumably taken at younger ages and discarded than after the change, the trend in the recruitment observed in Fig. 9 might be an artifact or at least somewhat exaggerated. Because of lack of information on the mortality rates at younger ages, we cannot estimate the effect of removal of younger fish by the fishery on the abundance figures at age 6. However, to some degree the effect would be minimized if we calculate the average catch per trip at ages 4, 5, and 6, and average them for each year-class. This has been done by using discard information for 1956, increasing the figures giving the numbers at each age landed proportionately, dividing them by numbers of effort units, and totalling the resulting figures by year-classes.

The average catches per trip for combined ages 4, 5, and 6 by year-classes have been plotted in Fig. 9 as well.

Each line in Fig. 9 demonstrates an upward trend in recruitment. Since the graphs are based on average catch-per-effort figures, we expect the actual upward trend to be even greater than shown in the figure; that is, to relate catch-per-effort figures to the abundance the figures should be multiplied by a factor ${}_iZ_j/(1-\exp-{}_iZ_j)$. This multiplier increases with the fishing mortality or effort. Hence application of this correction would make the upward trend even more pronounced than shown in Fig. 9.

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Since the catch-per-effort figures are subject to year-to-year variations in catchability and to sampling errors, we have also calculated virtual population size estimates following the method of Paloheimo (1958). This method assumes that we know the catches and both fishing and natural mortalities. The method is simple and based on the catch equation written in the following form:

$$\frac{F_j+M}{F_j} C_j = N_j - N_{j+1}$$

where N_j, N_{j+1} is the population size of a year-class at the beginning of the year j, j+1, and C_j is the catch from it. Hence by adding up all the annual catches multiplied by the correction factor from a year-class at and after age 6 we thus arrive at the estimated population size at the beginning of age 6. The correction factor with which catches are to be multiplied is the inverse of the fraction the fishing mortality is of the total.

The virtual population estimates have been calculated using M = 0.17 and q = 0.000048. Table VII gives the values of the population size estimates and the three-year running averages have been plotted in Fig. 10. They confirm the general upward trend in the recruitment. We note that the last value for 1961 given in Table VII is based on catches of fish between ages 6-10 only; however as shown in the 4th column age groups older than 10 contribute very little to the estimate.

For the 1949-55 year-classes we may also plot estimated "virtual population" abundance against the estimated abundance of their parental stock, the latter being simply the catch-per-effort figure in weight of mature fish landed. This results in a stock recruitment relationship shown in Fig. 11. While it is based on data for a few years only the plot in Fig. 11 supports our conclusion based on Fig. 10 suggesting that recruitment has gone up or that at the past levels of fish stocks in the Gulf there is an inverse relationship between the size of the stock and its filial population.

Growth and production

In assessing the production from a stock of fish the rate of growth is of primary importance. In Table VIII we have given the estimated average weights of cod at age for the years 1949-52 and 1955-65. From these figures average growth rates may be obtained. These have been calculated for age zero to age six and between ages 6 to 10 for each year-class. The average growth up to age 6 has been calculated by taking the natural logarithm of the weight of fish at age 6 and dividing the logarithm by 6. The average growth between ages 6 to 10 is calculated from

$$\frac{\ell n\, W_9 + \ell n\, W_{10} - \ell n\, W_6 - \ell n\, W_7}{6}$$

where $\ell n\, W_9$ is the natural logarithm of the average weight at age 9. This method of averaging gives the average exponential rate of growth per year. It amounts to the same as plotting the log weights against age and then calculating the slope of the line of best fit to the points; the fitting of the line to arrive at the slope is termed non-parametric (Madansky, 1959).

The resulting average growth rates have been plotted against estimated population densities in Fig. 12 and 13. All points given are three-year running averages. As the index of the population density, the catch per effort in weight at age 6 and at ages 6 to 16 has been used in comparison with rates of growth up to age 6 and rates of growth between ages 6 to 10 respectively.

Both Fig. 12 and 13 suggest an inverse relationship between rate of growth and density of stock. The correlation coefficients are $r = -.623$ and $r = -.558$. At 9 degrees of freedom the 5% significance point is at $r = \pm .602$; that is, one of the correlation coefficients is significant, the other just below the significance level.

It is of interest that the growth rates up to age 6 and between ages 6 to 10 are not necessarily correlated. This is in keeping with the suggested inverse dependence of growth on the population density; that is, at the high level of recruitment observed in the few recent years, the growth up to age 6 has been

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slow. After age 6 fish have been subject to intensive fishing which has reduced the population density and resulted in faster rates of growth. This suggests at least a partial independence of trophic or other population interraction between large and small fish.

To assess the effects of changes in rate of growth and recruitment on the yield from the stock and on its production, we have calculated the biomass elaborated by the stock. Had there been no changes in these parameters, the biomass elaborated by the stock, or what is termed production from the stock, should be reduced proportionately with the reduction in the population size by the fishery. Our calculations show, however, that the production has in fact increased.

The production has been estimated by multiplying the catch per effort in numbers at age for ages 6 and up each year by the estimated rate of growth (in weight at age) from that year to the next. The three-year running averages of the resulting estimates are shown below in Table 9.

Table 9. Three year running averages of the relative biomass elaborated (i.e. production) per year

Mid point	Production: relative increase in weight
1950	2450
1957	3382
1958	2793
1959	2830
1960	3177
1961	3285
1962	2631
1963	3998
1964	4110

The above production figures show that the combined effect of changes in growth and recruitment have resulted in an increase in the production of the area.

Discussion

The foregoing studies may be reviewed in the light of the ICNAF Mesh Assessment Report published in 1962 (Beverton et al., 1962). This report evaluated changes expected in the yield from fish stocks in the ICNAF area and in the Gulf of St. Lawrence cod stock in particular with reference to change in mesh size from the existing $4\frac{1}{2}$ inches to 4 or to 5, $5\frac{1}{2}$ and 6 inches. Minor benefits varying between 1 and 3% were predicted by an increase in mesh size while a small loss of about 6% was predicted if the mesh size were to be reduced to 4 inches. These predicted changes were based on calculations which assumed that a change in mesh size will not have any effect on the recruitment, growth, or natural mortality rate.

In the Gulf of St. Lawrence cod fishery the mesh size was changed in 1957. Just prior to that there had been an increase in the level of fishing effort due to a gradual build-up in the Canadian fleet and in fishing of the stock by European countries beginning about 1952. An increase in the mesh size has a tendency to reduce the effect of fishing on the stock by delaying the average age of first capture. In a sense, it is comparable to a reduction in the fishing effort on fish near the average age of first capture. This effect of the increase in the mesh size was more than counterbalanced by increases in the fishing effort. In fact, even the average age at first capture in the landings seems to have declined. Hence the predominant feature of the fishery since 1947 has been a steadily increased fishing at earlier ages notwithstanding the mesh size increase.

In reviewing the earlier assessment, it is important to compare the actual population changes with the premise on which that assessment was based, i.e. fixed rates of recruitment, growth and natural mortality. No new data are available on natural mortality rate.

There is little doubt that the recruitment has been progressively higher in the more recent years and is generally higher than in the earlier years. Fig. 11 suggests in fact that the higher population densities in the earlier years 1949-53

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may have had a depressing effect on the recruitment and that the increased recruitment in recent years may have been related to the reduction of the cod stock, concurrent with and apparently resulting from the increased fishing. There has also been a gradual cooling of the average water temperature during much of this same period which might in turn be expected to contribute to increase in cod production (Martin & Kohler, 1965). However, the hydrographic change has been slight and does not appear to be related directly to the growth rate changes which are known to have been responsive to food abundance changes. It is reasonable to suppose that at least part of this recruitment effect may similarly have resulted from food and population density interactions and thus be related to the fishery effects.

In general, it is expected that a lower population density would give rise to increased growth and vice versa. Our observations of the Gulf cod stock appear to confirm this. A higher rate of recruitment in the recent years seems to have resulted in a lower rate of growth up to age 6 while the increased fishing and concommittant lower population densities at fishable sizes seems to have resulted in an accelerated rate of growth of older fishes sustaining the fishery i.e. between ages 6 to 10. The overall effect of these changes appears to have led to an increased production and yield from the stock.

We can only speculate on the reasons for the recruitment changes and its implications for management of the 4T cod stock. It is not without importance to note two features. First, the large fish which formerly sustained the fishery were to a large extent fish (herring) feeders. These have now been virtually eliminated from the population, at no apparent sacrifice to overall yield. The second feature about food relations is that the large cod diet also consisted of substantial amounts of the same crustacean food which is the principal food of the smaller fish. Paloheimo & Dickie (1965) suggested that small fish are more efficient grazers of food and use it more efficiently for growth as well. It is tempting to speculate that the population response, resulting in larger total production & yields has been partly a result of the sharp decrease in the average fish sizes, due to fishing, involving changes in the utilization of the basic food supply.

In conclusion we may state unequivocally that the benefits of past and future mesh increases, predicted by the yield per recruit calculations, could not have been realized if the growth responses and recruitment changes observed in the 4T cod stock had also occurred. As noted earlier, the predominant feature of this fishery has been increased fishing and an effective drop in age at first capture. In such a situation the yield-per-recruit model suggests a possible decline in productivity. In fact productivity of the stock appears to have increased, attributable in large part to an increased recruitment. But concurrent with changes in recruitment and in fishing there were also changes in rates of growth possibly related to abundance and food interractions. These other changes were such that had the recruitment been stable their effects would still have resulted in increased production per recruit for increased fishing and effective lowering of the age of first capture. These trends are opposite to those predicted by the model. Our study therefore suggests the increase in the mesh size in the Gulf fishery effected in 1957 was justified only on account of the elimination of the high discards of smaller cod. It cannot be justified on biological grounds nor on the basis of a simple "savings effect".

Were the compensatory changes observed in the Gulf cod stock a result of the fishery effects, as we suggest here, any future increase in the mesh size would tend to lead to lowering of the production from the stock and to losses for the fishery. On the other hand whether an actual decrease in the mesh size or an increase in the effective effort could give even large compensatory production changes favourable to the fishery cannot be well established without further research. The implications of such a possibility are, however, of sufficient general importance to suggest that such study should be an important feature of any future research program.

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Table II. 4T Cod - Number per trip on basis of otter trawl, pair trawl and Danish Seine.

	Age																
Year	4[a]	5[a]	3	4	5	6	7	8	9	10	11	12	13	14	15	16+	
1949	715	-	222	292	433	675	1002	1123	491	537	340	160	244	164	10	25	5718
1950	826	385	149	387	353	592	859	474	976	300	484	207	79	493	382	171	5906
1951	1135	344	91	775	813	773	475	512	376	561	361	216	197	118	116	109	5493
1952	1149	2009	48	669	1974	901	472	465	399	373	522	264	158	49	48	105	6447
1953	395	749	14	69	719	1215	452	235	302	205	320	460	143	87	69	71	4361
1954	919	525	58	565	436	2046	1634	320	84	466	355	115	207	82	75	-	5457
1955	747	1880	49	413	1859	447	773	526	158	57	60	68	45	21	12	15	4503
1956	522	330	-	199	307	1265	557	790	687	145	75	51	116	90	33	44	4359
1957	935	769	9	385	666	320	1394	432	722	350	79	66	52	56	40	34	4605
1958	1163	1970	-	656	1932	912	304	969	218	206	116	47	12	12	2	5	5391
1959	835	3172	23	430	3137	2432	1022	258	517	128	109	48	6	2	15	-	8127
1960	930	1201	22	699	1186	1379	307	203	71	123	30	27	7	2	2	-	4558
1961	764	2542	-	621	2536	1719	1378	459	75	37	76	39	13	6	3	1	6963
1962	464	2724	4	463	2717	4263	1059	555	217	45	8	14	2	1	1	1	9350
1963	586	920	38	588	923	3783	2662	907	362	85	47	10	18	2	1	2	9428
1964		920	203	1247	919	951	2329	1437	498	191	60	20	8	11	3	3	7880
1965			38	1032	1134	1394	678	1619	864	358	106	62	20	1	5	6	7817

[a]Discards added to landings

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Table III. Calculations of catch per effort and total effort figures.

Year	Catch per unit effort 1st & 2nd quarters	Catch fraction 1st & 2nd qtrs	Catch per unit effort 3rd & 4th qtrs	Catch fraction 3rd & 4th qtrs	Weighted catch per unit effort	Relative units of effort: Total all gears	Relative units of effort: Total OT, pair tr., Danish seine	Relative units of effort: Canadian landings only
1948	1.77	.50	1.69	.50	1.74	2198	291	2198
1949	1.74	.50	1.61	.50	1.68	2883	440	2883
1950	1.52	.46	1.31	.54	1.46	3015	442	3015
1951	1.43	.46	1.30	.54	1.38	2524	722	2524
1952	1.70	.47	1.22	.53	1.45	2893	1082	2530
1953	1.23	.44	.95	.56	1.07	5506	3621	2958
1954	.65	.27	1.43	.73	1.22	5752	3794	3393
1955	.80	.32	1.19	.68	1.07	6462	4387	4012
1956	.97	.32	1.58	.68	1.38	8004	4970	4959
1957	1.24	.33	1.43	.67	1.37	6620	3472	5032
1958	1.06	.41	1.15	.59	1.11	8338	4752	5990
1959	1.30	.45	1.28	.55	1.29	6276	3679	4664
1960	.69	.46	.78	.54	.74	8973	5574	5467
1961	1.06	.49	.86	.51	.96	6831	4534	4422
1962	1.25	.49	1.15	.51	1.20	5528	3730	4298
1963	1.46	.56	.96	.44	1.24	5661	4232	4328
1964	1.25	.59	.86	.41	1.09	5555	4340	4587
1965	1.31	.63	.62	.37	1.06	5946	4815	5315

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Table IV. Estimated mortality rates at age and mean efforts

Year	Mortality at age 7/6 x_1	7/8 x_2	8/9 x_3	9/10 x_4	Mean Relative Effort
1949-50	+ .1757	- .8209	- .1347	- .5727	2949
50-51	- .2268	- .5225	- .2869	- .7403	2769
51-52	- .4573	+ .0048	- .2692	- .0212	2708
52-53	- .6235	- .5605	- .4004	- .5310	4200
53-54	+ .1458	- .5024	-1.2379	+ .3088	5629
54-55	- .8096	- .9707	- .5413	- .2194	6007
55-56	+ .2611	+ .0184	+ .2438	- .1064	7233
56-57	+ .0928	- .3424	- .1720	- .7074	7312
57-58	- .0693	- .3886	- .6367	-1.1647	7479.
58-59	+ .1112	- .1603	- .6275	- .4568	7307
59-60	-1.1147	-1.6095	-1.2837	-1.4398	7624
60-61	- .0090	- .5726	-1.0051	- .6387	7902
61-62	- .4861	- .9088	- .7424	- .4893	6180
62-63	- .4732	- .1531	- .4232	- .9365	5595
63-64	- .4976	- .6180	- .6033	- .6311	5608
64-65	- .3369	- .3638	- .5126	- .3355	5750

Table V. Analysis of covariance of mortalities against mean fishing efforts

Data from Table IV

Age	Mortality sum of squares	Cross product	Effort sum of squares	Regression coefficient q	Sum of squares due to regression	Residual sum of squares
7/6	2.34970	+ 7.96926	4688.6828	- .001699	.005881	1.014581
8/7	2.54741	-13.01654	4688.6828	+ .002776	.015692	1.090633
9/8	2.40373	-39.02843	4688.6828	+ .008324	.141086	.902839
10/9	2.77592	-32.95006	4688.6828	+ .007027	.100563	1.105004
10/6	1.41974	-19.25932	4688.6828	+ .004108	.034359	.582228

Mean total mortality rates: Age 6-10		Based on Table IV	Based on catch curve
	1949-51	Z = .39	Z = .12
	1949-52	Z = .32	Z = .12
	1955-65	Z = .51	Z = .59
	1962-65		Z = .67

Table VI. Analysis of variance of mortality rates given in Table IV.

	Sum of squares	d.f.	Mean sum of squares	F
Total	8.884	51		
Years	5.466	12	.455	7.00 *
Ages	1.095	3	.365	5.62 *
Within	2.323	36	.065	
Years Total	5.466	12		
Between 1949-52 1955-65	.315	1	.315	.67
Within	5.151	11	.468	

* significance at 5%

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Table VII. Virtual population size estimates at age 6

Year	Summation for 6 and over x	Summation up to age 10 y	y/x %
1949	7609.31		
1950	7881.23		
1951	5447.22		
1952	9004.37		
1953	27854.88		
1954	26939.81	26004.15	96.5
1955	11762.44	11181.17	95.0
1956	26962.21	26146.95	97.0
1957	6043.58	5859.28	96.9
1958	14540.80	13952.43	96.0
1959	25390.17	24520.45	96.6
1960	27432.59	26645.65	97.1
1961	29775.65	29775.65	100.0

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Table VIII. Mean weight at age - 4T Cod - 2nd and 3rd quarters combined.

Year	Age - Years 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16+
1949			1.62	2.07	2.85	3.64	4.69	5.56	6.50	9.19	10.08	11.63	14.43	17.10	8.39	29.57
1950			1.82	2.39	2.47	3.36	3.74	4.25	5.33	5.95	7.11	12.23	12.71	7.55	10.27	8.33
1951			1.41	2.26	2.78	3.80	4.51	5.16	5.82	7.27	7.90	11.02	10.04	11.76	13.30	13.12
1952			1.65	1.95	2.78	3.82	4.86	5.14	5.44	6.79	6.59	9.91	9.77	11.80	11.14	13.21
1953			1.26	2.05	2.72	3.63	5.25	6.03	6.62	7.58	6.53	8.19	10.78	13.21	12.23	12.19
1954			1.48	1.70	2.33	3.31	4.17	5.31	5.26	6.14	6.33	8.22	8.36	5.90	5.72	-
1955			1.81	2.68	2.88	4.09	5.69	7.70	9.55	10.22	8.97	11.89	14.91	13.25	18.49	12.84
1956			-	2.12	3.68	4.29	5.31	7.87	9.92	10.82	12.23	11.39	14.43	14.19	14.53	9.92
1957			1.98	2.27	3.03	4.76	5.31	7.09	9.48	11.89	13.07	12.06	15.37	11.26	14.05	26.60
1958			-	2.02	2.86	3.92	5.00	5.95	7.24	9.12	9.74	13.85	13.34	13.39	21.18	18.78
1959			1.38	1.83	2.47	3.29	4.25	5.51	6.73	7.90	9.33	12.49	24.13	23.12	19.06	-
1960			1.69	1.73	2.33	3.35	4.34	5.61	7.70	7.36	10.70	11.26	11.06	10.58	17.65	23.12
1961			-	1.64	1.99	2.74	3.82	4.86	8.26	7.52	8.91	8.12	12.75	14.05	15.62	17.10
1962			0.94	1.40	1.88	2.40	3.33	4.45	4.95	7.30	12.98	8.46	15.57	28.93	27.34	32.06
1963			1.98	1.43	1.73	2.09	2.74	3.90	5.56	8.16	7.68	14.14	8.06	16.93	24.13	16.45
1964			1.30	1.37	1.85	2.19	2.67	3.36	4.67	7.87	9.92	13.07	19.36	14.57	14.82	23.31
1965			1.04	1.42	1.68	2.09	2.64	3.15	4.15	5.28	8.26	10.34	4.09	29.32	17.87	18.89

Note: 1953 and 1954 based on very unreliable sampling.

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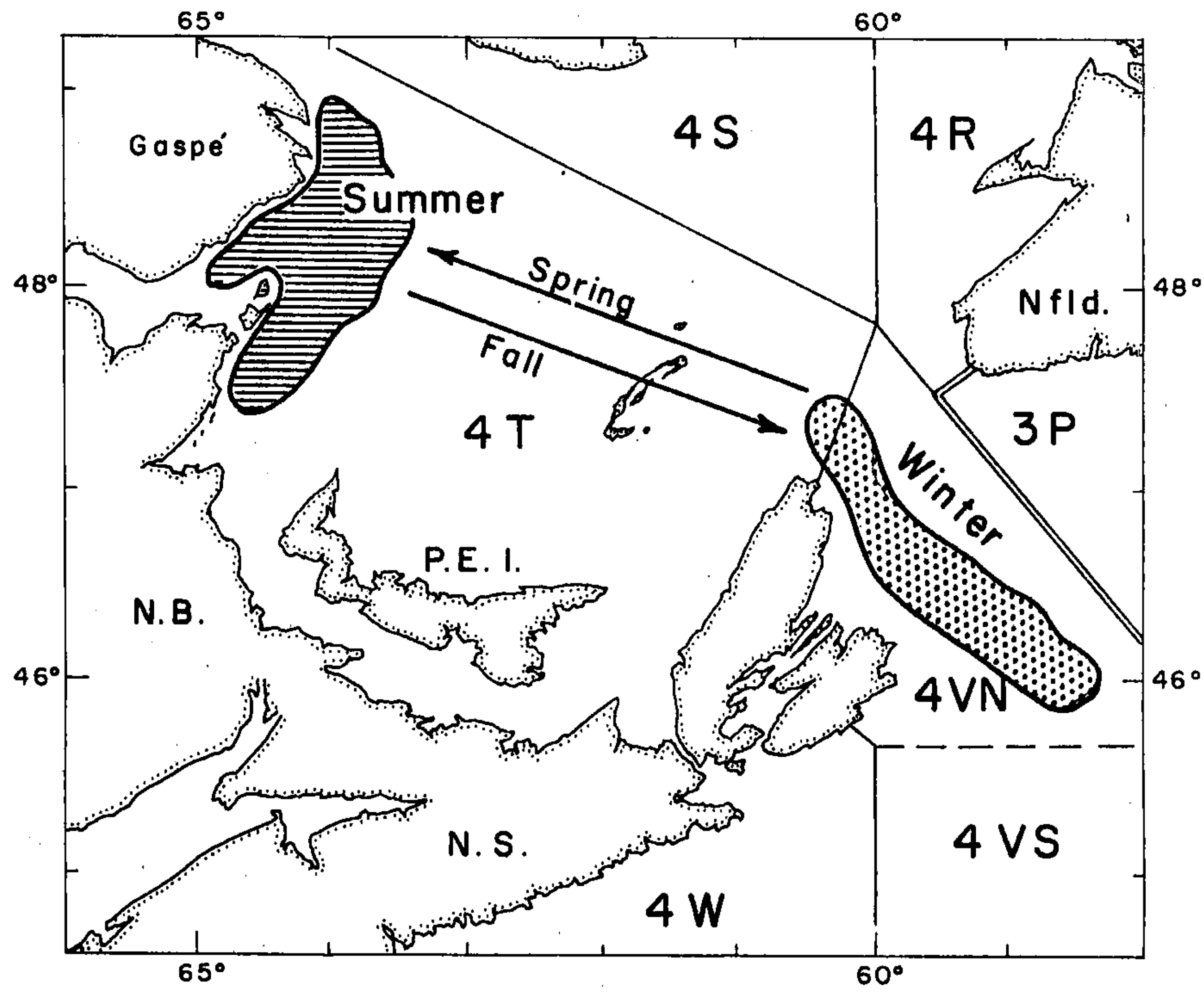

Fig. 1. Migrations of the southern Gulf of St. Lawrence cod stock.

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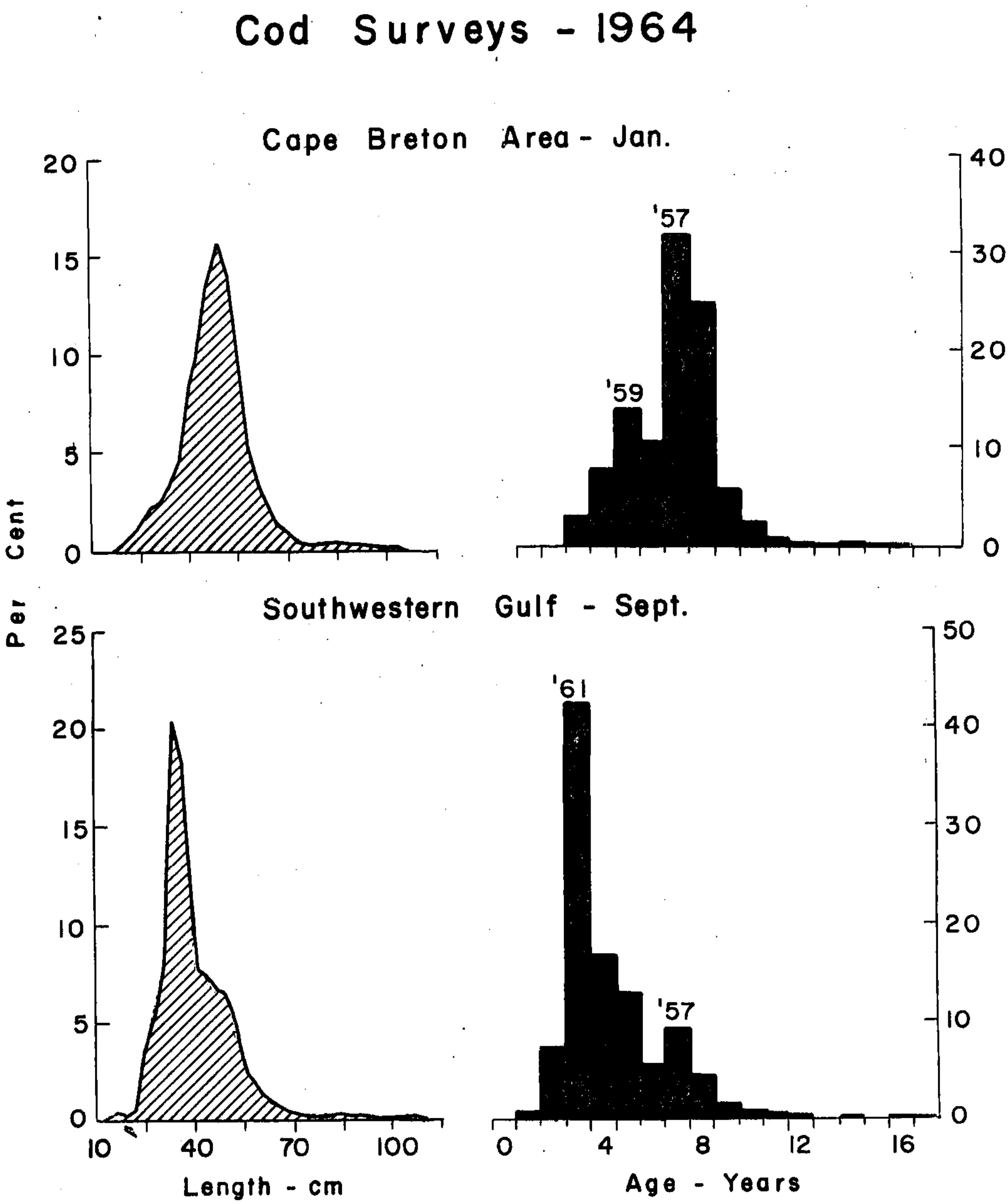

Fig. 2. Lengths and ages of Division 4T cod caught by a research vessel.

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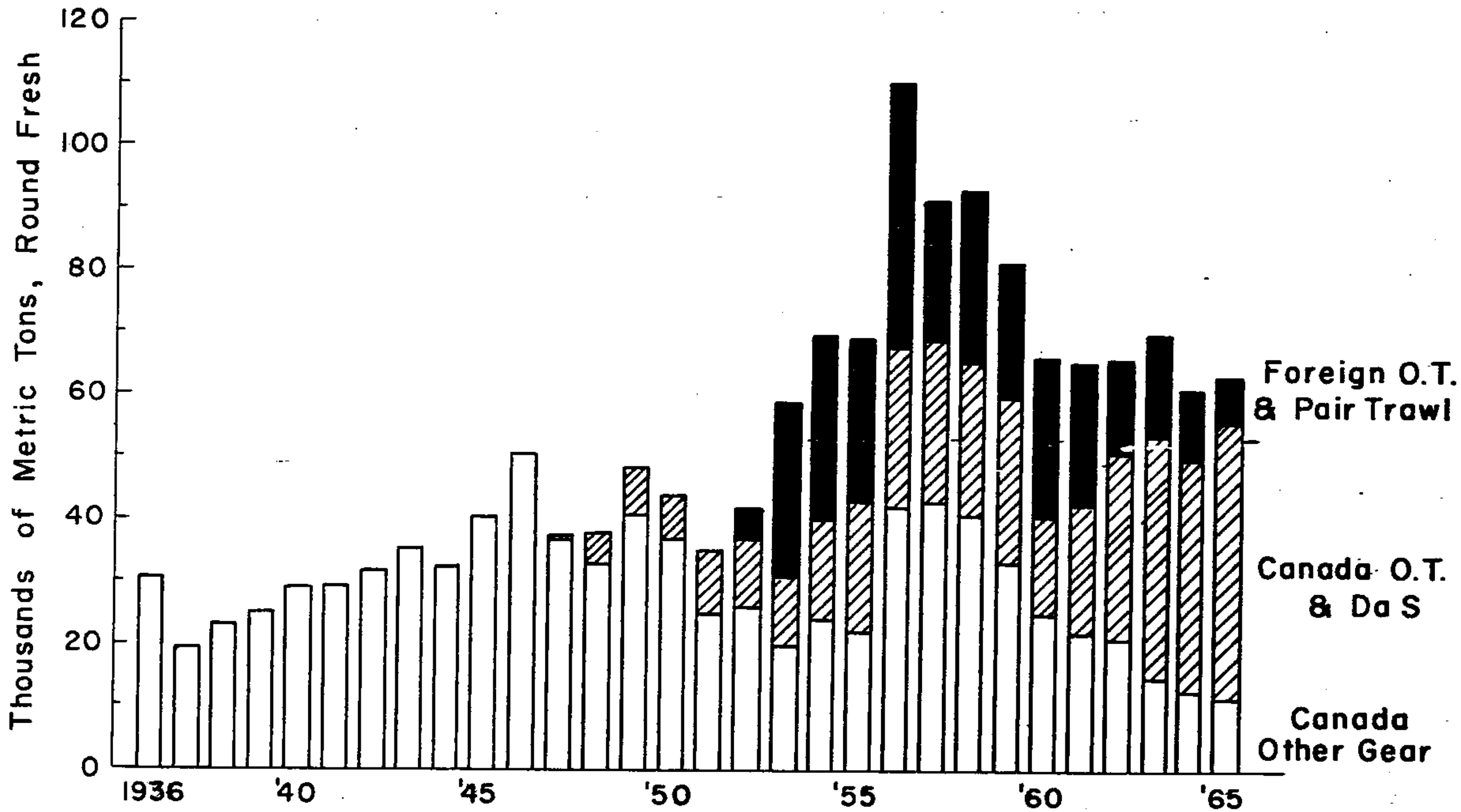

Fig. 3. Annual landings of southern Gulf of St. Lawrence cod:
1952-53 landings are yearly totals for 4V;
1954-57 landings are 1st quarter 4Vn and 4Vs;
1958-59 landings are 1st quarter 4Vn and 4V (4Vs not included);
1960-65 landings are 1st quarter 4Vn only;
all 4T landings are annual.

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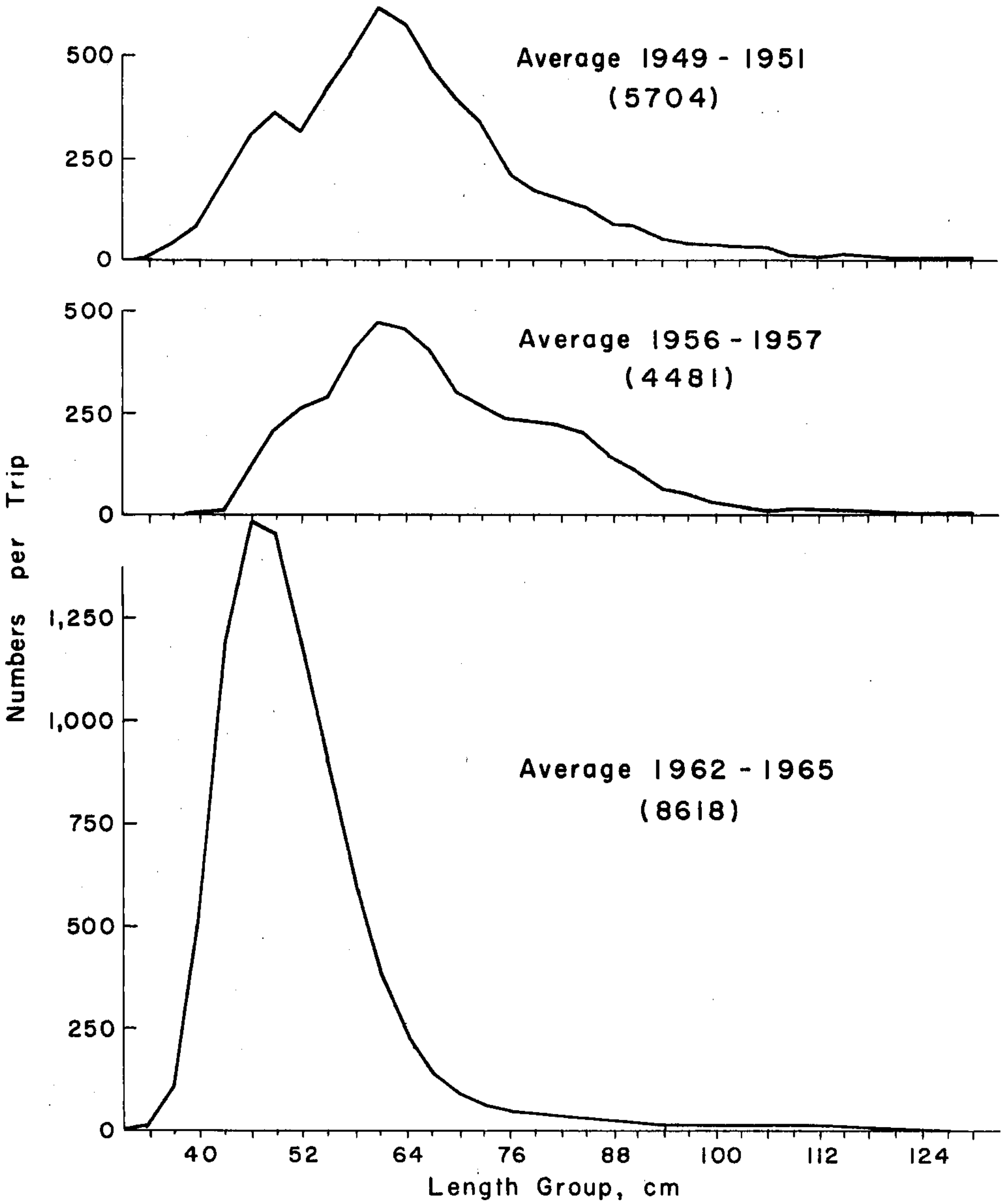

Fig. 4. Length frequencies of Division 4T cod in numbers per trip.

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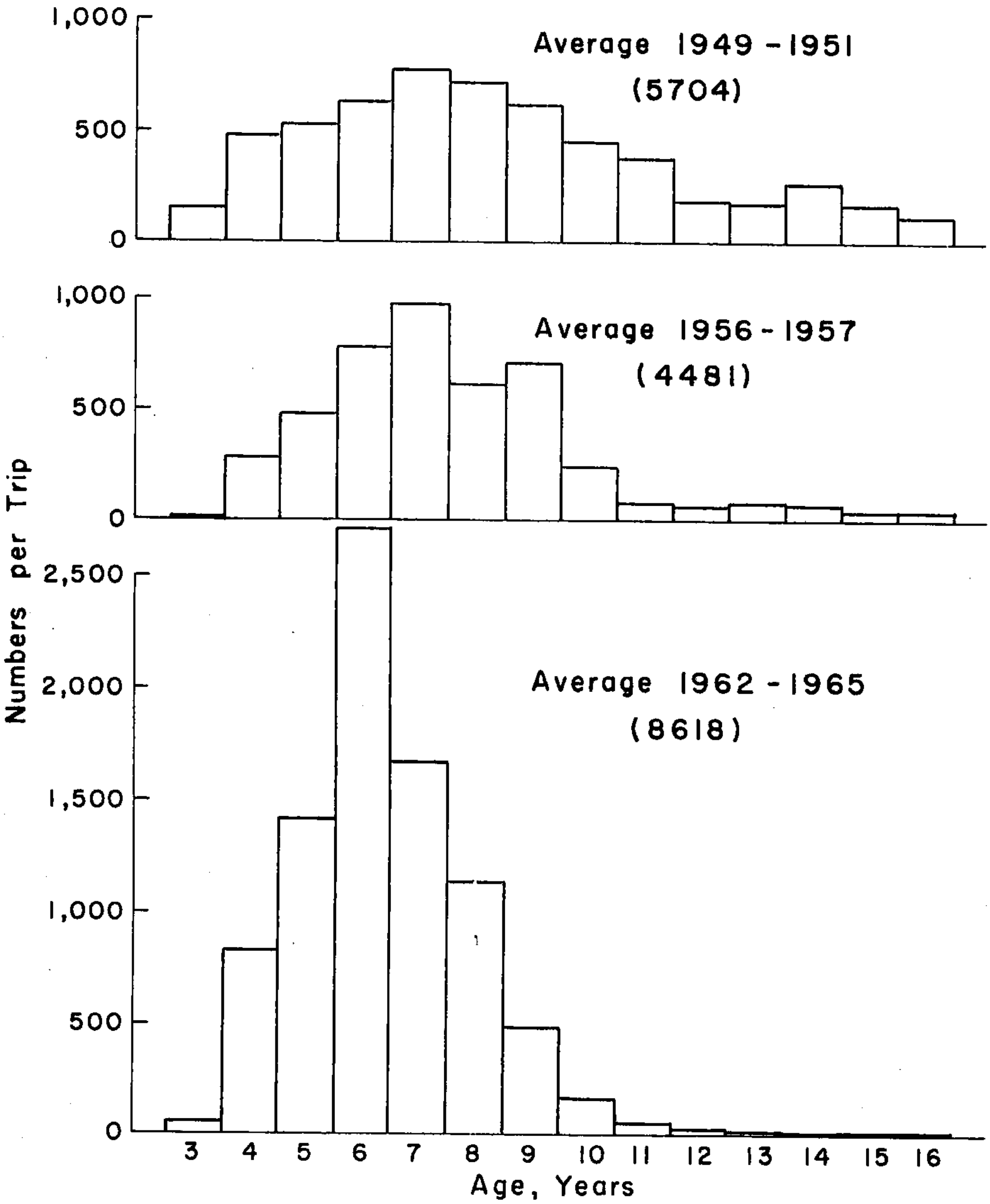

Fig. 5. Average age composition of Division 4T cod stock.

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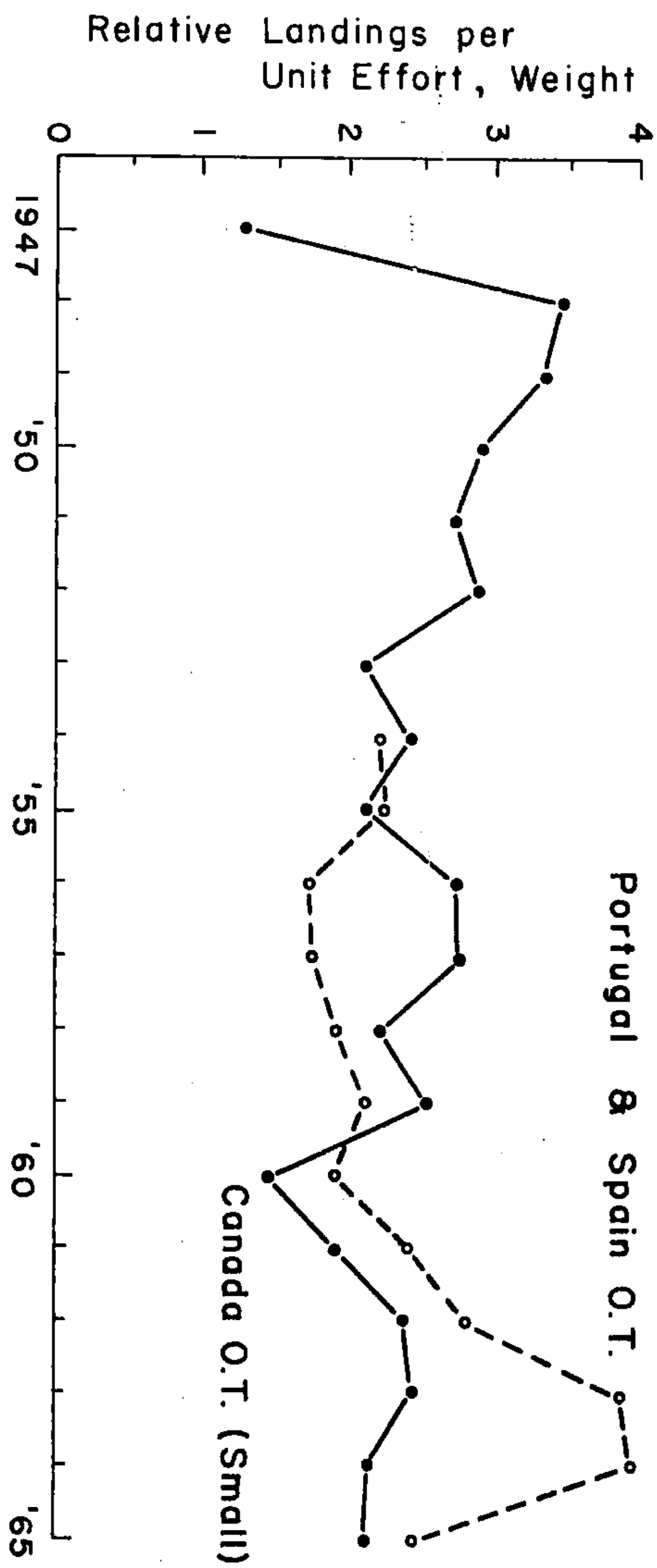

Fig. 6. Landings per unit effort of Division 4T cod.

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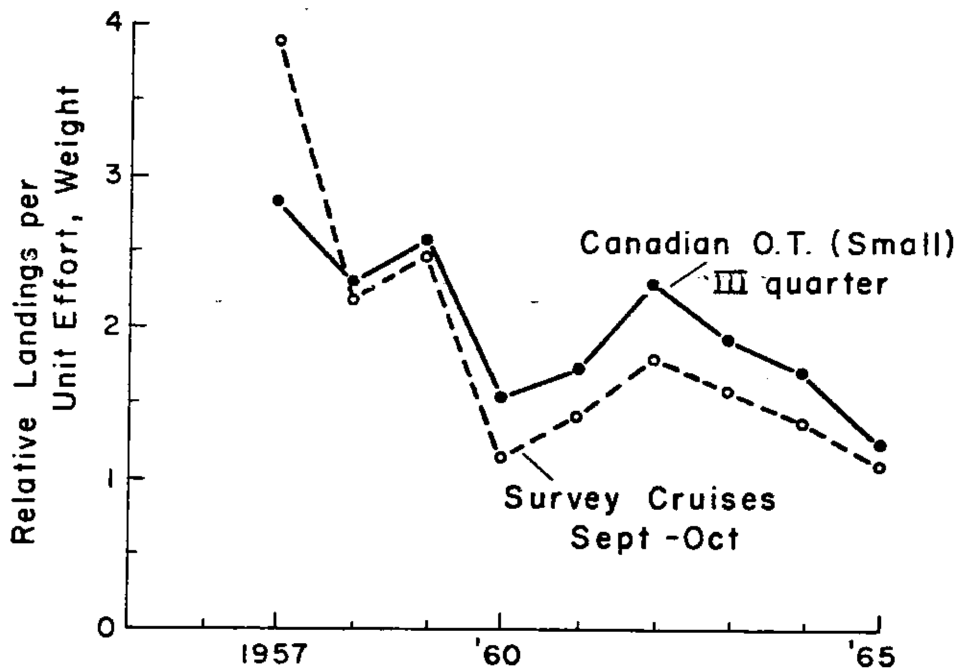

Fig. 7. Relative landings per unit effort for commercial and survey cruises from the Division 4T cod stock.

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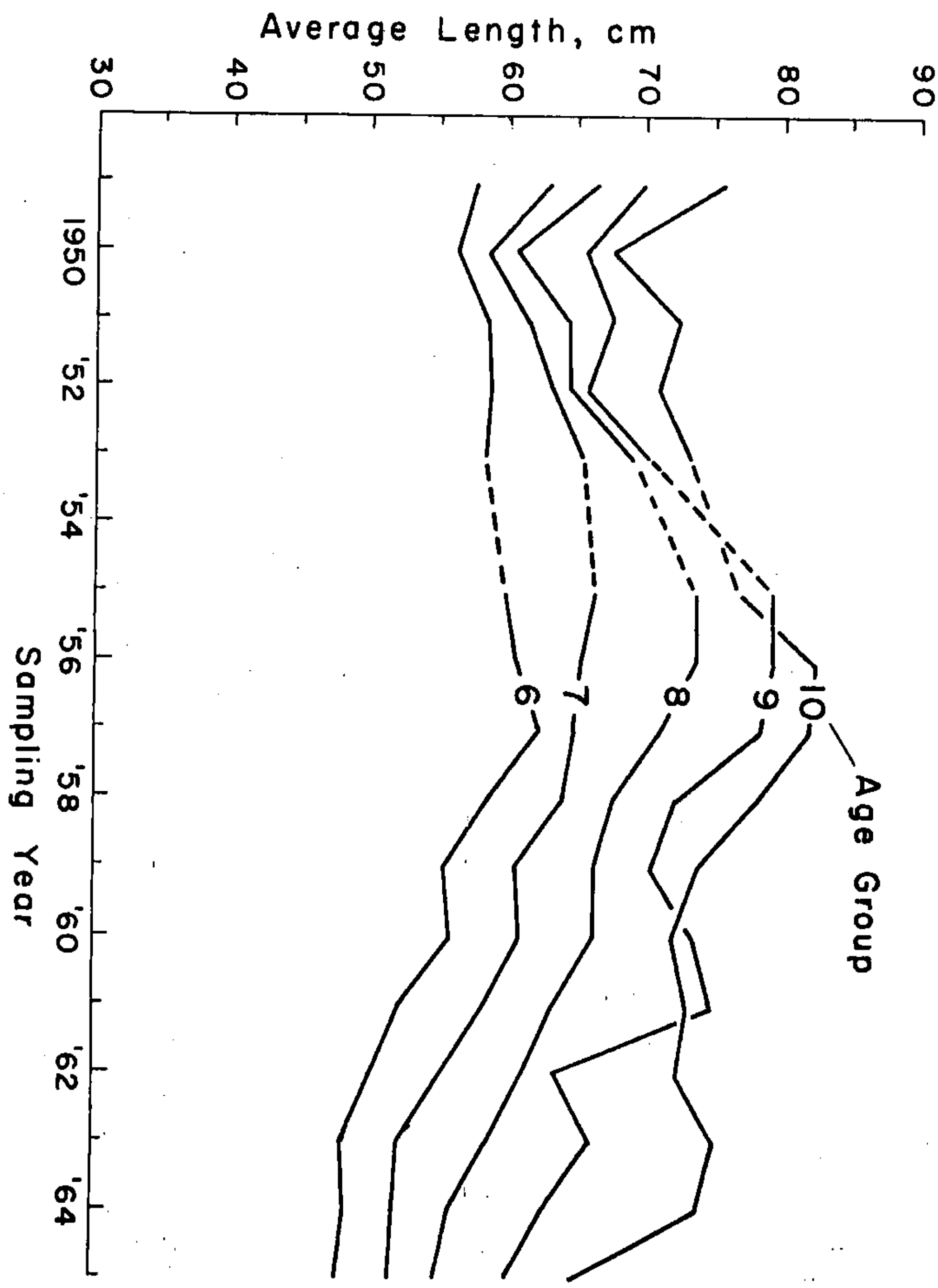

Fig. 8. Division 4T cod age-length data.

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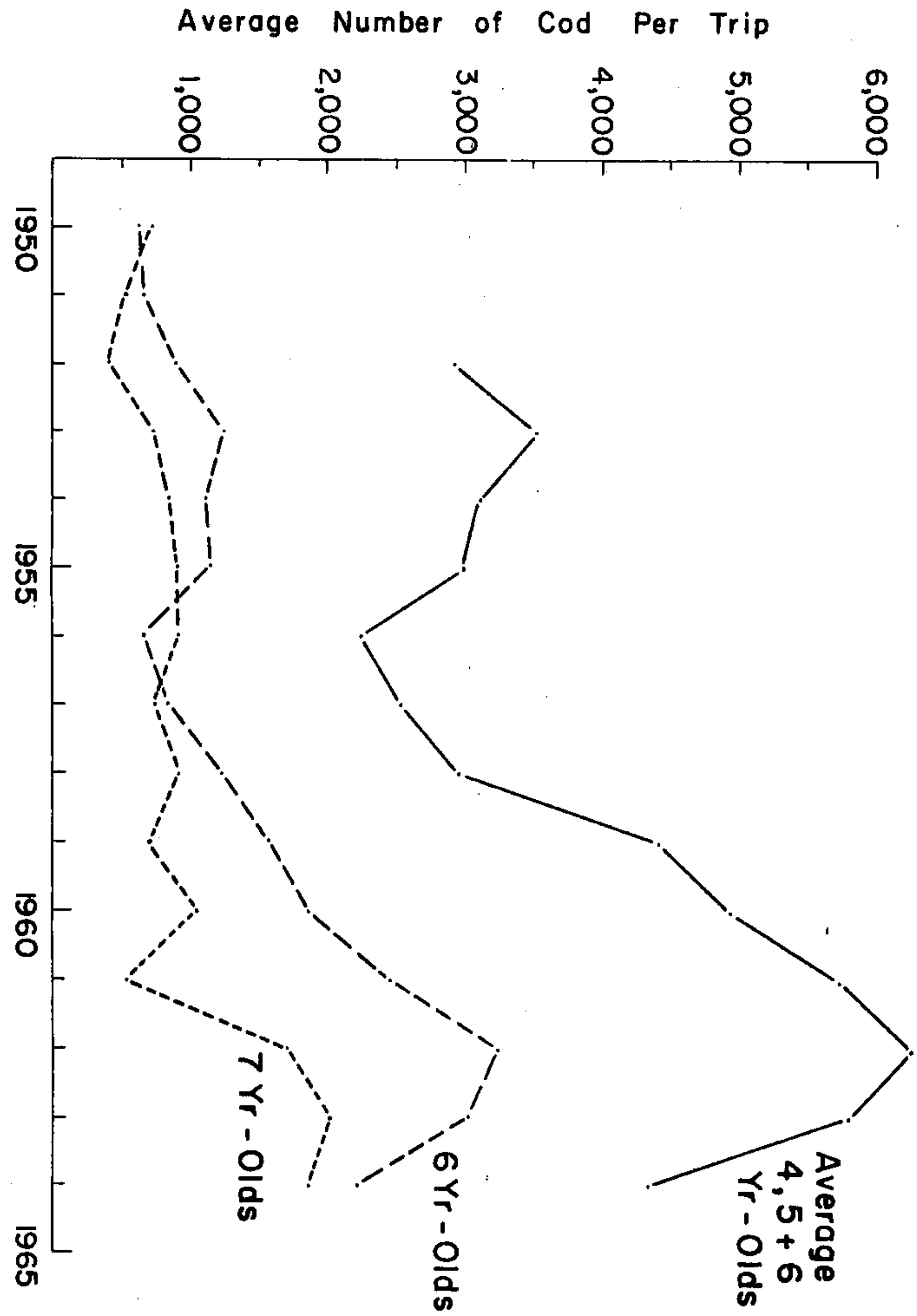

Fig. 9. Three year running average of catches per effort in numbers for ages 6, 7, and ages 4, 5, and 6 combined.

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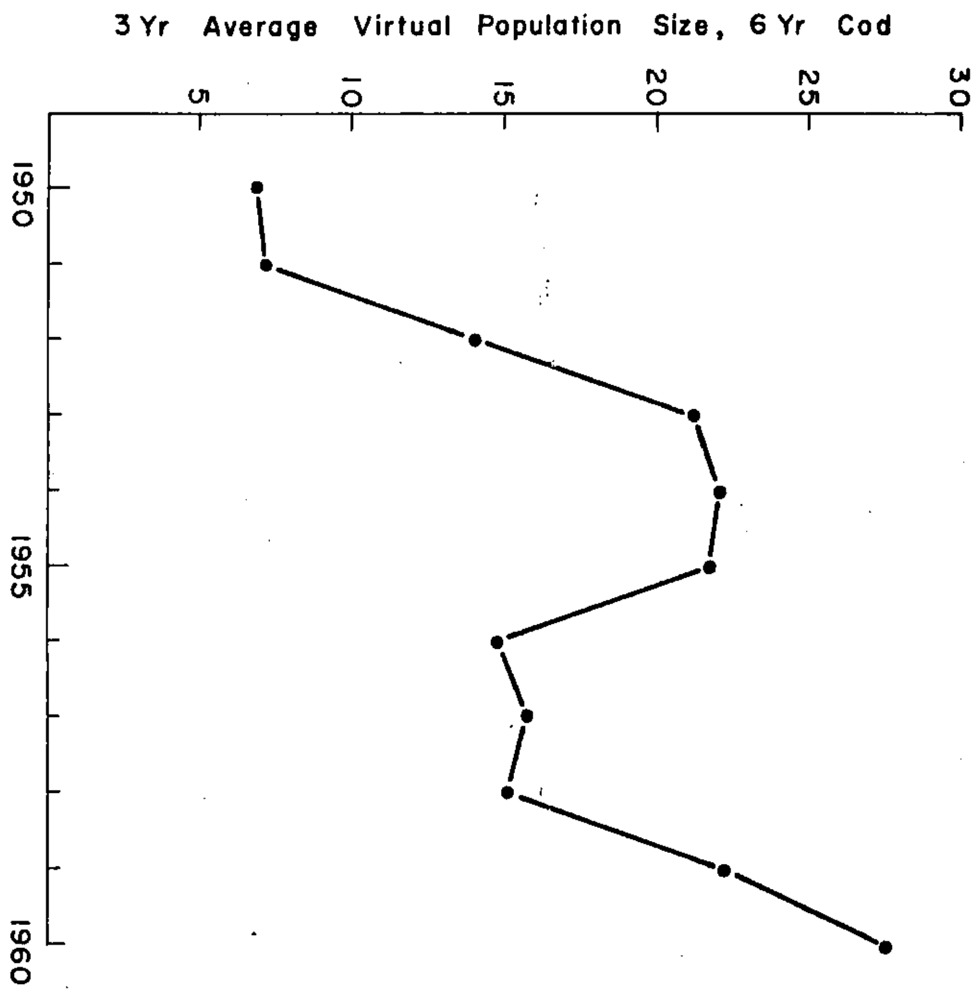

Fig. 10. Three year running averages of the virtual population size estimates at age 6.

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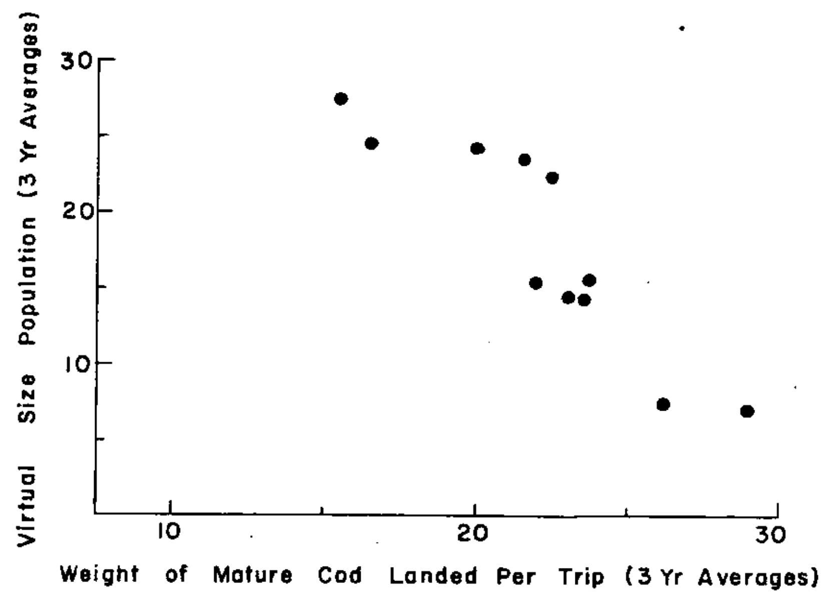

Fig. 11. Stock-recruitment relationship. Virtual population estimates at age 6 plotted against weights of 6-16 year old Cod landed per trip 6 years earlier. Figures given are three year running averages.

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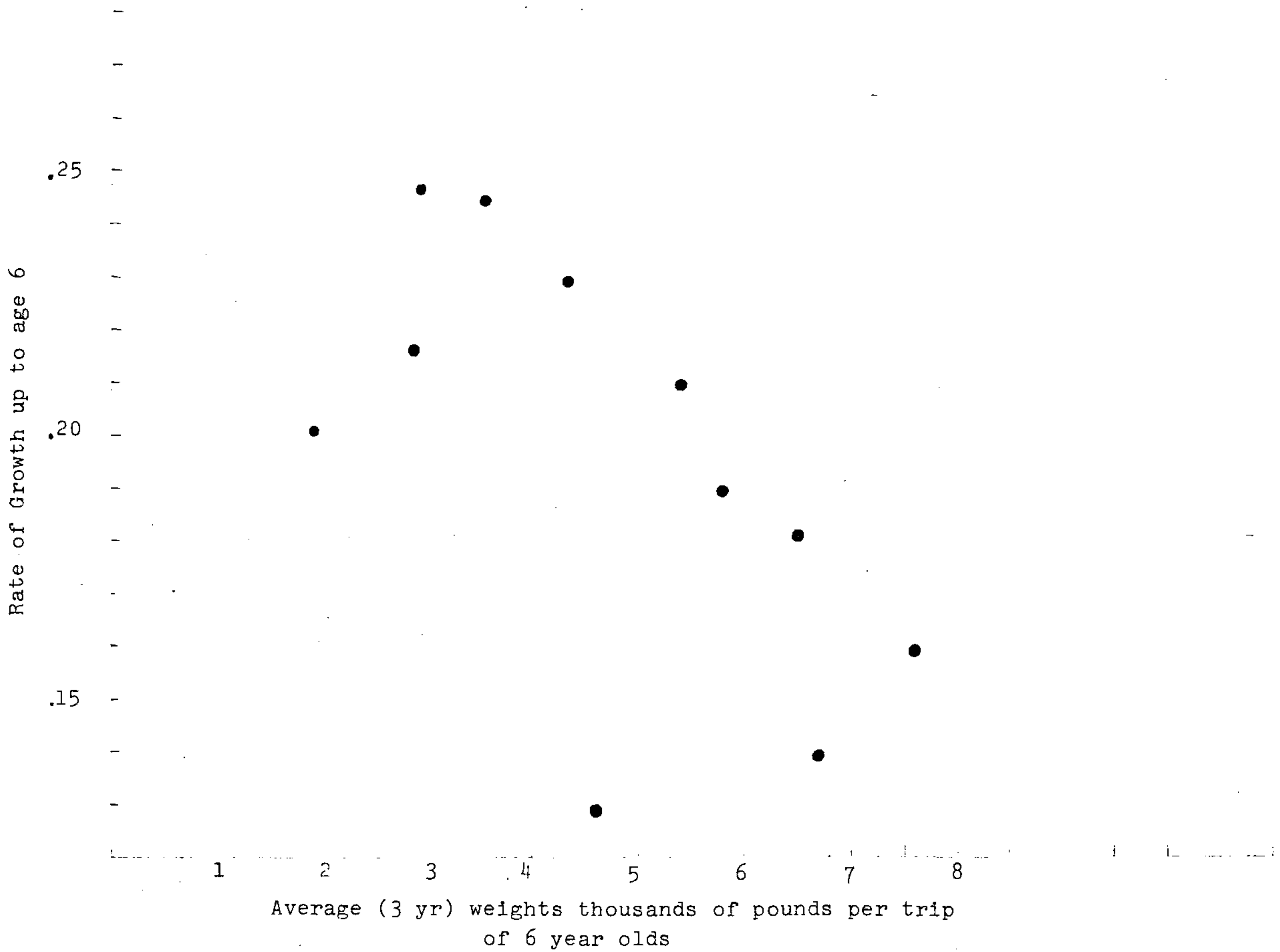

Fig. 12. Average growth rates up to age 6 plotted against estimates abundance in weight at age 6. All figures are three year running averages

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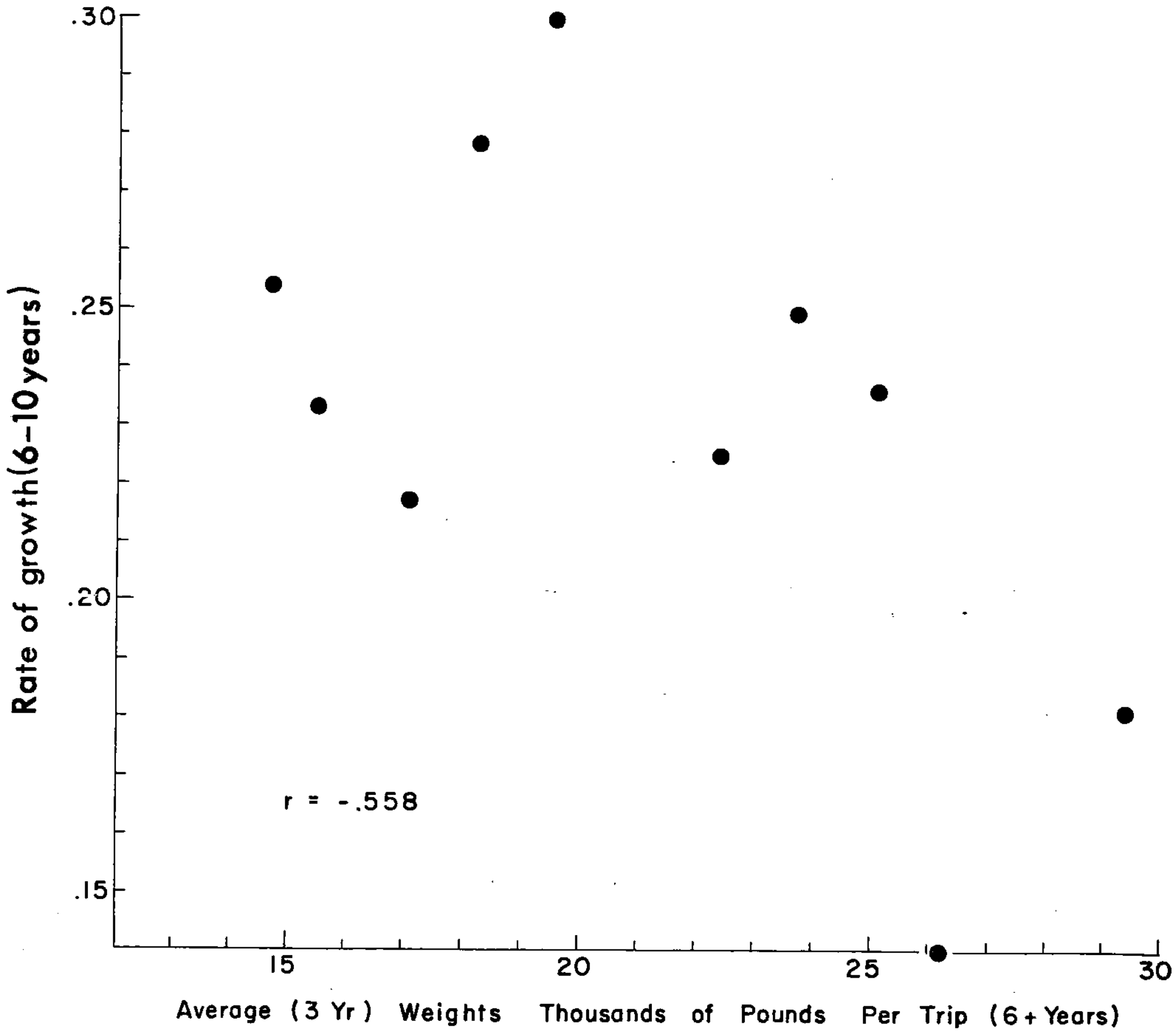

Fig. 13. Average growth rates of 6-10 year-old fish plotted against estimated abundance of 6-16 year old fish. Figures given are three year running averages.